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13. ABSTRACT *(Maximum 200 words)*

There are numerous situations, from picking fruit to flying a plane, that require an observer to find a target item in a field filled with distracting items. Guided Search (GS) is our model of this visual search process. This project aims to develop the next generation of that model. In the past year, progress has been made in three areas: 1) The GS computer simulation has been improved, notably by equipping it with the ability to learn how to select useful information from the available input channels. 2) Our study of individual differences between subjects indicates that the differences between subjects indicates that the differences revealed by standard search paradigms are probably mere noise. However, we can modify the usual paradigm by using larger display set sizes. This produces reliable individual differences that can be used to evaluate theories of search. 3) There are many tasks that require search through visually complex technical information. Using electrical diagrams as an example, we have developed techniques to speed search by graphical recoding of diagram information. We do this while preserving the standard structure of the diagrams. Our goal is "hybrid search" in which human and computer both contribute to the success of the search.

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Developing Guided Search 3.0
The Next Generation of a Model of Visual Search
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Annual Report: 1993-1994

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The goals of this project are to improve and extend our Guided Search model of visual attention and, in so doing, to expand the general understanding of human visual search behavior. The early stages of visual processing can be characterized as parallel processors, operating across the entire visual field at one time. Parallel processing seems to be limited to a set of fairly basic properties like color, motion, orientation, etc. Later stages in processing, mediating more complex perceptual tasks, appear to be far more limited in their capacity. They appear to process only a single item or a small area at one time. The basic idea of Guided Search is that the output of the parallel processes can be used to *guide* the attentional deployment of the limited capacity processes so that this limited capacity is used in an effective manner. As one example, consider the search for an apple in the refrigerator. Even if there is no parallel processor that can discriminate tomatoes from apples, intelligent use of a color processor can restrict processing to the red items and avoid wasting resources on the analysis of broccoli or bananas.

The Guided Search model provides a detailed and testable description of the deployment of attention in human subjects doing visual search tasks. We have just published the account of the second generation of the model and its simulation [Wolfe, 1994 #2657]. We show that it can successfully simulate a wide range of search behavior. In this project, we are developing the third generation of Guided Search. The original project had three specific aims: 1) To revise and enhance the Guided Search simulation to handle more search tasks and to produce more accurate simulations of human behavior. 2) To study individual differences in search behavior as a source of insight into the search mechanism, and 3) to explore the possibilities of *hybrid* search systems where the interaction of computer and human observers allows for better search than either computer or human alone. We will discuss progress in each of these areas.

The Guided Search Simulation

Greg Gancarz (a graduate student funded by this project) has had prime responsibility for advancing the Guided Search (GS) simulation. Greg has completely rewritten the code for the simulation, moving it from our Macintosh computers to our Sun Sparc10. The simulation now runs much faster making it easier to generate model predictions. Another addition has been graphical input and output. The revised simulation allows more direct control over the free parameters in the model. Finally, the code should be easily exportable to other labs that might want to test the simulation.

Turning to the scientific substance of the simulation project, most of the details of the current simulation are as described in Wolfe (1994). There have been some interesting changes. For example, GS proposes that attention is guided by a weighted average of the outputs of the parallel feature processors. Those feature processes come in two forms: bottom-up processes that guide attention toward loci of abrupt change and top-down processes that guide attention toward loci having a target attribute (the correct color or

orientation). Consider a search for a red vertical item among green vertical and red horizontal distractors. Since the display is a jumble of reds and greens, verticals and horizontals, bottom-up, local contrast information is essentially useless. Top-down information is useful, however. The target will be red, not green and it will be vertical, not horizontal. To work efficiently, attention should be guided by the top-down signals with the contributions of the bottom-up signals minimized. In the published GS2 simulation, the weights are imposed by fiat. In the newer version, the simulation learns the appropriate weights for each task. To learn the weights, a signal to noise ratio is computed for each parallel feature representation on each target-present trial. The weights are then adjusted up or down based on the signal strength. Weights are averaged over a set of trials to make changes gradual . We plan to look in human data for evidence of a similar weight-adjusting mechanism.

Other changes are also underway. The published simulation calculates attention guiding activations only at the known loci of items. In a world of continuous images rather than discrete items, this may be an over-simplification. Accordingly, we are now using operations that occur at all locations whether or not they contain stimuli. For example, all locations are now subject to "noise", not only the location of items. We have also modified the model's early vision "channels" for orientation and color in an effort to make them more realistic. One aspect of the current representation of orientation has not been changed but, perhaps, should be. In our experiments and in our modeling, we have used simple lines as our oriented stimuli. Lines, rotated through 180 deg, return to their original orientation. The same is not true for most objects. A coffee cup, rotated 180 deg has quite different properties. We plan to explore the implications of a 360 deg orientation space in the coming year. In color, we plan to move from a very unrealistic 2D color space to a 3D space.

Individual Differences in Visual Search

Patricia O'Neill, a post-doctoral fellow in the lab, has had primary responsibility for our studies of individual differences in visual search behavior and their relationship to the Guided Search. Our basic premise is that individual differences are meaningful and are not merely noise. Two experiments have been run. Experiment 1 explored the reliability and stability of individual differences observed in standard visual search experiments. We tested 30 subjects on eight different search tasks: 3 feature searches (size, color and orientation), 3 conjunction searches (targets defined by a pairwise combination of the three features) and 2 serial searches (search for a 2 among 5s with all stimuli upright or rotated 90 deg.) Set sizes of 4, 10 and 16 were used. The dependent measure is the slope of the function relating reaction time (RT) to set size (SS). For each condition, a measure of reliability was obtained by splitting each subject's data into even-numbered and odd-numbered trials and computing an RT x Set Size slope for each half of the data. If the slopes are statistically reliable, then the slope derived from the even-numbered trials should be the same, or nearly the same, as the slope derived from the odd-numbered trials. Correlating the slopes obtained from the even-numbered trials with those obtained from the odd-numbered trials indicates the degree of reliability of each condition.

The reliability for the feature searches averaged 0.24 (where 1.0 indicates perfect reliability, and 0.0 no reliability). In conjunction searches, reliability was high for the blank (target-absent) trials (avg. = 0.87) but low for the target present trials (avg. = 0.22) The serial search slopes were moderately reliable, with an average reliability of 0.40 for the target present trials, and 0.80 for the target absent trials. Performance across the conditions appeared to be unrelated (mean intertask correlation = 0.14).

The high reliabilities for blank trial slopes suggests that variability across subjects in these conditions represents stable individual differences. The low reliability of the target present

slopes means that, given the parameters used in this experiment, differences between subjects in these tasks may be nothing but noise. Experiment One was designed to use set sizes and numbers of trials typical of those reported in this literature. While the results suggest that great caution should be used in interpreting the individual differences in the published literature, they do not mean that there are no individual differences of interest to be found on target present trials for conjunction and feature searches. Slope estimates are likely to be quite unstable when a relatively small range of set sizes is used. A small change in the mean RT for one set size can produce a large change in the slope. In an effort to improve reliabilities in our data, we ran a second experiment.

In Experiment Two, data were collected from 40 subjects for another eight search tasks. There were three conjunction tasks (two Color X Orientation tasks and a Size by Orientation task). There were two "odd-man-out" tasks. In these tasks, subjects search for an odd item in a subset of the elements on the screen. For example, in one of these tasks, the target was a red item of orientation X deg and the distractors were red items of orientation Y deg and green items of orientation X deg. The orientations, X and Y, changed from trial to trial so that subjects could not know the orientation of the target before the trial. Once the stimulus appeared, however, subjects could search for an item of odd orientation in the set of red items. These experiments produce results that are different from those in a standard color X orientation conjunction (Friedman-Hill and Wolfe, 1994). In the second odd-man-out tasks, subjects searched for the odd texture in the horizontal items. There were two identification tasks in which subjects merely had to name the red letter or the oblique letter. In these tasks, all that was required was that attention be directed to *any* red or oblique letter. No other search was required. Finally, there was one serial search task for the 2 among 5s. Set sizes ranged from 27 to 100 for all but the serial task, which used the typical set sizes of 4, 10 and 16.

As in Experiment One, the reliability for the blank trials was high, averaging 0.88 across all conditions. Compared to Experiment One, the mean reliability for the target present trials improved, increasing to 0.50. Larger set sizes appear to make the slope estimates more stable. As a result, it becomes possible to examine the pattern of individual differences.

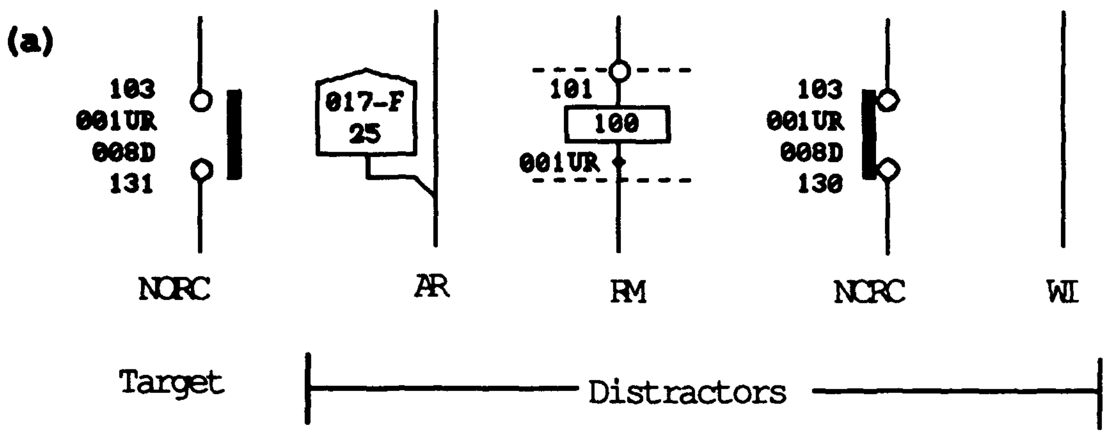
The pattern of correlations of the slopes over all the conditions was examined with structural equation modeling (specifically, Lisrel). The object of such modeling is to find underlying factors that might explain the pattern of individual differences across tasks. To give a somewhat trivial example, if the subject population contained subjects with various color vision deficiencies, we would expect a factor related to color vision to explain some of the variability on those tasks involving color but not on the other tasks. (In fact, all subjects were screened for color blindness and all were in the normal range).

Turning to a more realistic example, GS proposes that it is the top-down component of the parallel processing of basic feature information that is important in guiding attention in conjunction search tasks and in odd-man-out tasks but not, for example, in serial tasks. We analyzed the pattern of correlations across tasks to determine if a model with components derived from GS faired better in accounting for the data than models with other components.

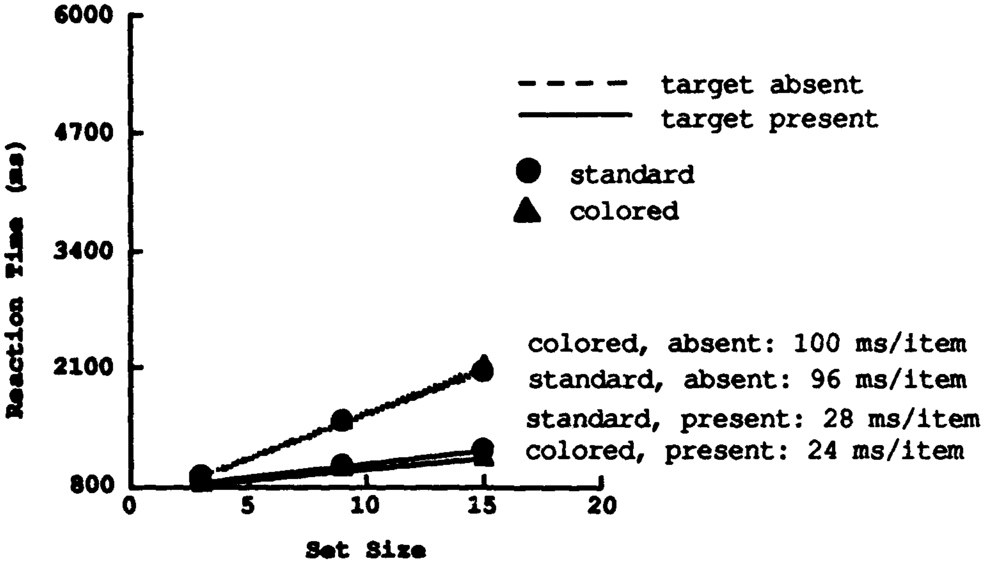
Lisrel analysis indicated that the individual differences were not due to variation in some single underlying factor such as a motor skills ability nor were they explained by a model that proposed differences only in the processing of basic feature information (i.e. a "color" factor, an "orientation" factor, and so on). A model based on Guided Search provided the best fit to the data of any model tested. It had factors for attentional deployment, top-down activation for orientation and for color, a search termination factor, and two task-specific factors.

Hybrid Search

The idea of Guided Search is that the parallel stage of visual processing can guide the deployment of attention. The basic idea of "hybrid search" strategies is that the computer as a partner in visual search tasks providing additional guidance to a human searcher. Given our knowledge of the human search capabilities and limitations, we can design artificial aids to guide attention in a more efficient fashion. As a start in this direction, Laurent Ponthieu and I have done a series of pilot experiments with electrical diagrams. The choice of stimuli is driven by Dr. Ponthieu's interests. He came as a visitor from Electricité de France, the French electric power utility. There, complex electrical diagrams are read by technicians to troubleshoot electric systems. A typical diagram might be a hundred pages long with each page containing dozens of symbols and text captions. This seems like a natural place to try hybrid search since the technician might benefit from the help of a computer in navigating through the diagrams. We began with two visual tasks that are part of reading the diagrams. The first task was a shape (form) search for one component among others as illustrated below.

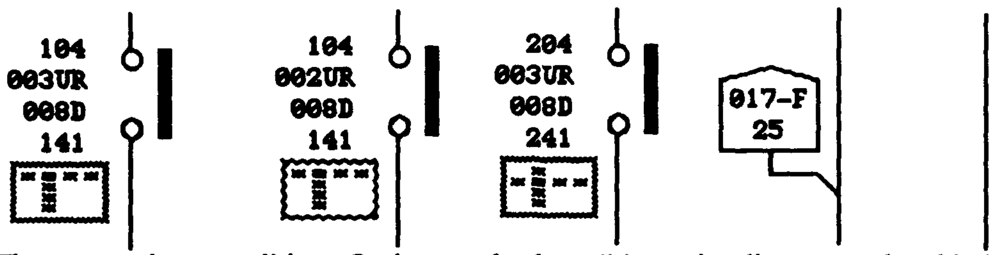


The target is a "normally open relay contact" (NORC). The distractors are: "off-page connector" (AR), "relay magnet" (RM) and "normally closed relay contact" (NCRC). The NCRC component is obviously the most confusable with the target. The manipulation in this experiment was to color code different subcomponents. That is, all of the wires were purple, all of the large vertical bars were green and so forth. While subjects reported that the color coded case seemed more pleasant, it made no significant difference to the task as shown in he figure below:

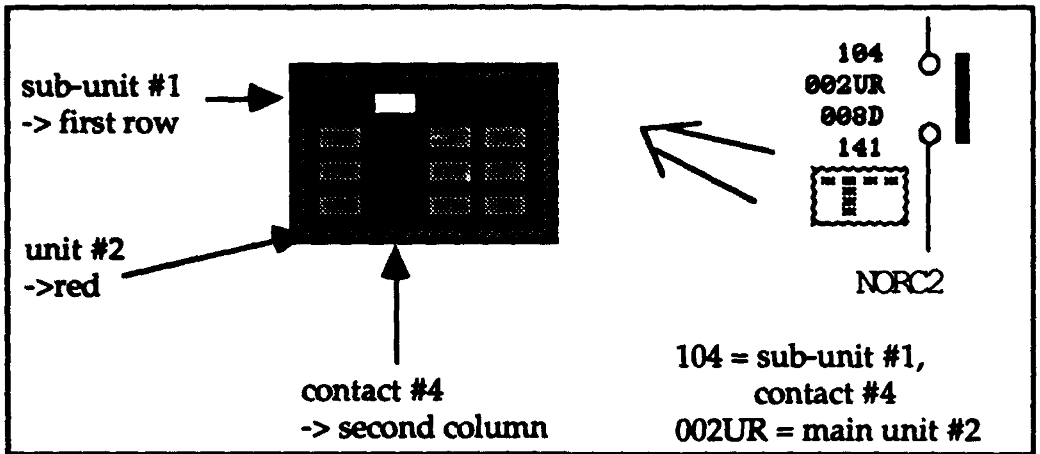


Apparently, subjects could pick out the contacts just as well in the black and white rendition. The search is slow, we assume, because Ss need to make a relatively slow, relative position judgment once they have directed attention to a large vertical bar.

In the second task, subjects look for a particular open switch as defined by its label. In the example given below, the target is the switch with a "1" in first position in the first row of text and a "3" in the third position of the second row. (These numbers label the identity of a switch and give connection information.).



There were three conditions. In the *standard* condition, stimuli were rendered in black and white. RT x set size functions had slopes of 190 msec/item for target trials and 360 msec/item for blank trials. These values suggest a serial search *with saccadic eye movements* through the set of switches. In the *colored* condition, the relevant digits in the text were given a different color. The resulting improvement to 170 msec/item on target trials and 320 msec/item on blank trials is only significant on the blank trials. Apparently, the time-consuming portion of this task is not the search for the right bit of text. In the final, *recoded* condition, the rectangular graphic shown below the text was added. It is shown in more detail below:



This recodes the text information in a manner described in the accompanying technical report. For the present, the important aspect of the recoding is that it takes the reading task and transforms it into a search for a complex conjunction of basic features like color and shape. The result was an approximate 3-fold reduction is slopes to 66 msec/item for target trials and 140 msec/item for blank trials. These results suggests that we may be able to add symbolic information in the blank spaces of the diagrams that will guide search in a useful way. Dr. Ponthieu has returned to France but we plan to continue to collaborate on this project. His more detailed report is included as an appendix.

Conclusion

Guided Search continues to be a useful model of visual search behavior. It is quite widely cited in the attention literature. In the past year, I have been invited to give talks on Guided Search at the Human Factors meeting (Seattle, Oct. '93), at a conference on "Converging Operations in the Study of Visual Attention (U. Illinois, May '94), at a conference on "Models of Sensory-Motor Coordination and Interactive Vision" (Telluride, CO, July, '94), as well as at a variety of colloquium talks. We believe that we are well on the way to a 3rd generation of the model.

In addition to Dr. Ponthieu's report, several papers and preprints accompany this report. They are:

Wolfe, J. M. (1994). Guided Search 2.0: A revised model of visual search. *Psychonomic Bulletin and Review*, 1(2), 202-238.

Wolfe, J. M. (1993). Guided Search 2.0: The Upgrade. *Proc. of the Human Factors and Ergonomics Society*, 37th annual meeting, 1295-1299.

Wolfe, J. M. (1994). Extending Guided Search: Why Guided Search needs a preattentive "item map". In A. Kramer (Ed.), Converging operations in the study of visual selective attention. Washington, D C: American Psychological Association., in press

Wolfe, J. M. (1994). Visual search in continuous, naturalistic stimuli. *Vision Research*, 34(9), 1187-1195.

Wolfe, J. M., Friedman-Hill, S. R., & Bilsky, A. B. (1994). Parallel Processing of Part/Whole Information in Visual Search Tasks. *Perception and Psychophysics*, 55(5), 537-550.